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X-670-71-168
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NASA TM X- 65523

AN UNUSUAL ABSORPTION FEATURE IN THE FAR UV SPECTRUM OF EARLY-TYPE SUPERGIANTS

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APRIL 1971

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FACILITY FORM 602
N71-24959 (ACCESSION NUMBER)
(THRU)
14 (PAGES)
G3 (CODE)
TMX 65523 (NASA CR OR TMX OR AD NUMBER)
29 (CATEGORY)

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by

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ABSTRACT

The OAO-II satellite has been used to obtain far ultraviolet spectrum scans of five early-type Ia supergiants. The data reveal the presence of a distinct, broad absorption feature centered near 1739 Å. This feature is unique in that it remains essentially constant in strength, breadth and central position over the spectral type range B0Ia to A2Ia. The feature is not present in the B and A main-sequence spectra we have examined. It probably does not arise in the general interstellar medium because there is no correlation with reddening or with the strength of Lyman α. It may be formed in circumstellar clouds surrounding the supergiants. The conjecture that the feature is produced by the formaldehyde molecule is discussed.

Apparent ultraviolet flux distributions for five early-type supergiants are plotted in Figure 1. Similar distributions for five main-sequence stars are given in Figure 2. All of the data were obtained with spectrometer 2 of OAO-II (Code et al. 1970). The effective resolution of the instrument is

12 Å. (B.W. Savage, private communication 1971); consecutive data points are obtained at increments of about 10 Å.

The spacecraft boresight tracker was used for the spectral scans of all five supergiants. It is thus reasonable to assume that the wavelength scale and zero point determined for one scan applies equally well to all. This is of particular importance in the case of the scan of α Cyg, for which a scale and zero point could not be determined unambiguously from identified spectral features. We have used line identifications and observed wavelengths given by Morton et al. (1968) for ϵ Ori to establish a scale of 10.5 Å per grating step and an average absolute wavelength at each grating step. The scale is confirmed by the apparent separations of conspicuous features in the B3Ia, B5Ia and B8Ia spectra which may be attributed chiefly to C II, Si III and Lyman α.

Numbered vertical lines in Figures 1 and 2 indicate twenty wavelengths near which prominent absorption features appear in one or more of the spectrum scans. Possible major contributors to these features are listed in Table 1. The multiplet numbers are from the Ultraviolet Multiplet Tables (Moore 1950, 1962, 1965). No attempt has been made to list the many lines of the second and third spectra of the metals which fall in the regions of interest. Such lines are probably present but better resolution than that available is required to show them.

The feature at position 3 in Figure 1 has been cross-hatched to facilitate identification. It appears as a well-defined, pointed dip with a central flux which is 0.80 to 0.85 of the flux in adjacent regions outside the feature. The apparent total width of the feature lies in the range 20 to 40 Å. We estimate the central wavelength to be 1739 Å. We believe it unlikely that this estimate could be in error by more than $\pm$ 8 Å; most of this error is systematic owing to our inability to specify increments less than one grating step.

The constancy of the zero point is determined by the positional stability of the boresight tracker. At 12 Å resolution, one cannot distinguish between a simple broad absorption feature and a pattern of narrow features spread more or less symmetrically over the apparent line width. In accepting either possibility one must be prepared to explain the unique constancy of the feature over the spectral type range B0Ia to A2Ia.

No feature of comparable strength occurs near λ1739 in the scans of main-sequence stars shown in Figure 2. Broad, shallow undulations do occur in the vicinity of 1739 Å, especially at the earlier spectral types. However, these are not so constant in appearance or position as the feature observed at 1739 Å in supergiants. The shallow undulations may be attributed to relatively weak stellar lines from the ions listed in Table 1.

We do not believe that any of the possible contributors listed for position 3 in Table 1 could account for the λ1739 feature in the supergiants. If the Ni II lines were responsible, one should see even stronger features at 1710 Å and 1788 Å. These lines are present weakly, if at all, in the late B type spectra. Similar considerations apply to Ni III and Mn II. We note that Morton *et al*.(1968) did not find the N I (UV9) lines in the spectrum of ϵ Ori; they did indicate that N III (UV19) may appear in ϵ Ori in the vicinity of 1750 Å. Lines of N III are reported by Lamers (1971) to be present in the visual spectrum of ϵ Ori. It is not plausible that the ultraviolet N III lines could persist to spectral types B8Ia and A2Ia. We conclude that the feature at 1739 Å is probably not stellar in origin.

The λ 1739 feature is probably not of general interstellar origin for its intensity does not correlate with reddening nor with the strength of interstellar Lyman α. The data in hand

are not sufficiently extensive, however, to allow a firm judgement to be made. The most heavily reddened star considered here is δ Sco, E(B-V) = 0.18. The λ1739 feature is not present in its spectrum scan, see Figure 2.

A third alternative is that the feature is formed in circumstellar clouds surrounding the early-type supergiants. The extensive mass loss from B0 and O9 supergiants observed by Morton (1967) and others lends plausibility to the existence of such clouds.

It has been called to our attention (B.D. Donn, private communication 1971; Gentieu and Mentall 1970) that the wavelength 1739 Å corresponds closely to that of a relatively strong, broad (about 40 Å) absorption feature in laboratory spectra of formaldehyde (H_2CO). The existence of formaldehyde in the interstellar medium has been established from radio observations (Snyder et al. 1969; Palmer et al. 1969). If the feature at 1739 Å does arise from H_2CO which somehow has been produced in a circumstellar cloud, one should also see relatively sharp absorption features near 1752, 1556, 1525, 1396, 1372 and 1287 Å. We cannot rule out the existence of these features on the basis of our present observations or those of Morton et al. (1968). However, the interpretation of the λ1739 feature as arising from H_2CO presents some problems. The estimated mean lifetime of an H_2CO molecule, unprotected from ultraviolet radiation, in the general interstellar medium is about 45 years (Stief et al. 1971). The net rate of formation over dissociation of H_2CO would have to be sufficient to maintain a column density of about 10^{15} cm^{-2} in order to produce the observed feature.

The hypothesis that the feature at 1739 Å is circumstellar in origin bears up well under criticism, but the identification of the feature is not certain. We will not be able to reject conclusively the somewhat improbable possibility that λ1739 is

the result of a fortuitous blend of several lines, which individually vary with spectral type but which collectively produce the more or less constant pattern observed in the supergiants at low resolution, until higher resolution spectra are available from future spacecraft missions.

The present data demonstrate once more how much stronger the absorption lines are in supergiant spectra than in main-sequence spectra. This fact poses interesting problems in the theory of stellar spectra.

We wish to express our appreciation to A.D. Code for generously granting us time as guest observers with the OAO-II Wisconsin spectrum scanner. We thank T.E. Houck, M. Molnar and A. Holm of the University of Wisconsin and S.R. Heap of the Goddard Space Flight Center for their help in obtaining the observations.

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TABLE 1

POSSIBLE CONTRIBUTORS TO THE PROMINENT ABSORPTION FEATURES

Position	Position Wavelength (Å)	Possible Contributors	Multiplet	Wavelength (Å)
1	1804	Ca II	11	1808, 1815
		S I	2	1807
		N III	22	1804, 1806
		Ni II	2	1804
		* Ga II	4	1799, 1814
		Si IV	23	1796, 1797
		Ni III	14, 20	1792 - 1801
		* Zr III	2, 3	1790 - 1805
2	1771	P I	1	1775-1788
		Ni II	3	1774
		* Sr II	4	1770, 1778
		Al II	5	1764-1768
		Ni III	14, 21	1761-1787
		C II	10	1760, 1761
		* Zr III	2,3,11,12	1759-1783
3	1739	N III	19	1748-1752
		N I	9	1743-1745
		Ni II	4, 5	1742-1755
		Mn II	13	1734-1738
		Ni III	15, 21	1725-1752
4	1713	Al II	6	1719-1725
		N IV	7	1719
		Si II	10	1711
		Fe II	37	1710, 1725
		Ni III	15, 16	1710-1722
		S I	10	1706, 1707
		Ni II	4,5	1703, 1710
5	1671	Ne II	7	1682, 1688
		P I	2	1675-1680
		* Zr III	4	1675, 1676
		Si IV	27	1673
		Al II	2	1671
		A III	6	1670-1676
		S I	11	1667
		C I	2	1656-1658

TABLE 1 (continued)

Position	Position Wavelength (Å)	Possible Contributors	Multiplet	Wavelength (Å)
6	1634	Ca II	1, 5	1644-1652
		Mn III	21	1643-1651
		He II	12	1640
		Si IV	28	1635
		*Zr III	29	1631,1638
		Fe II	8,42,43,68	1623-1650
7	1613	Al II	9	1626
		*Sr II	5	1613,1620
		*Zr III	29	1612,1621
		Fe II	8, 43	1608-1622
		Mn III	18	1602-1627
		*Sc III	1	1598-1610
8	1571	Ca III	4	1563
		Si II	11	1563
		A II	14	1560,1575
		C I	3	1560-1561
		Fe II	44,45	1559-1588
		Mn III	19	1558-1578
9	1545	Ca II	6	1554,1555
		C IV	1	1548,1551
		Al II	10	1540
		*Ga II	5	1535
		P II	1	1533-1544
		Si II	2	1533
		Si IV	24	1533
		*Sr II	6	1531,1538
10	1508	*Ga II	5	1505,1515
		P III	6	1502-1505
		Ni II	6,7	1500,1511
		Ti III	3	1499
11	1477	Si II	12	1485
		S I	3,4	1474-1487
		Ni II	6	1468
		Ti IV	3	1467,1469

TABLE 1 (continued)

Position	Position Wavelength (Å)	Possible Contributors	Multiplet	Wavelength (Å)
12	1456	Ni II	7	1455
		Ti III	5	1455
		Ti IV	3	1452
		S I	12	1448
13	1424	Si II	13	1439
		Ca II	7	1433-1434
		C I	65	1432-1433
		Si III	9	1417
		*Ga II	2	1414
		S I	5,6	1413-1437
		Fe II	47	1413-1425
		N I	10	1412
14	1398	Si IV	1	1394,1403
		Cl I	1	1390-1397
		S I	6,7	1386-1413
		Mn II	14	1386
15	1372	S I	7	1382
		P III	7	1380-1382
		Mn II	14	1378-1383
		Ni II	8,9	1370-1381
		Si IV	19	1366-1369
		Cl I	1,2	1364-1380
		Mn III	8	1361-1372
16	1335	Ca II	2	1342
		Cl I	2	1336-1352
		P III	1	1335-1345
		C I	4	1329-1330
		Ti III	4	1328
		N I	11	1327-1328
		C II	1,11	1324-1336
		S I	8	1324,1327

TABLE 1 (continued)

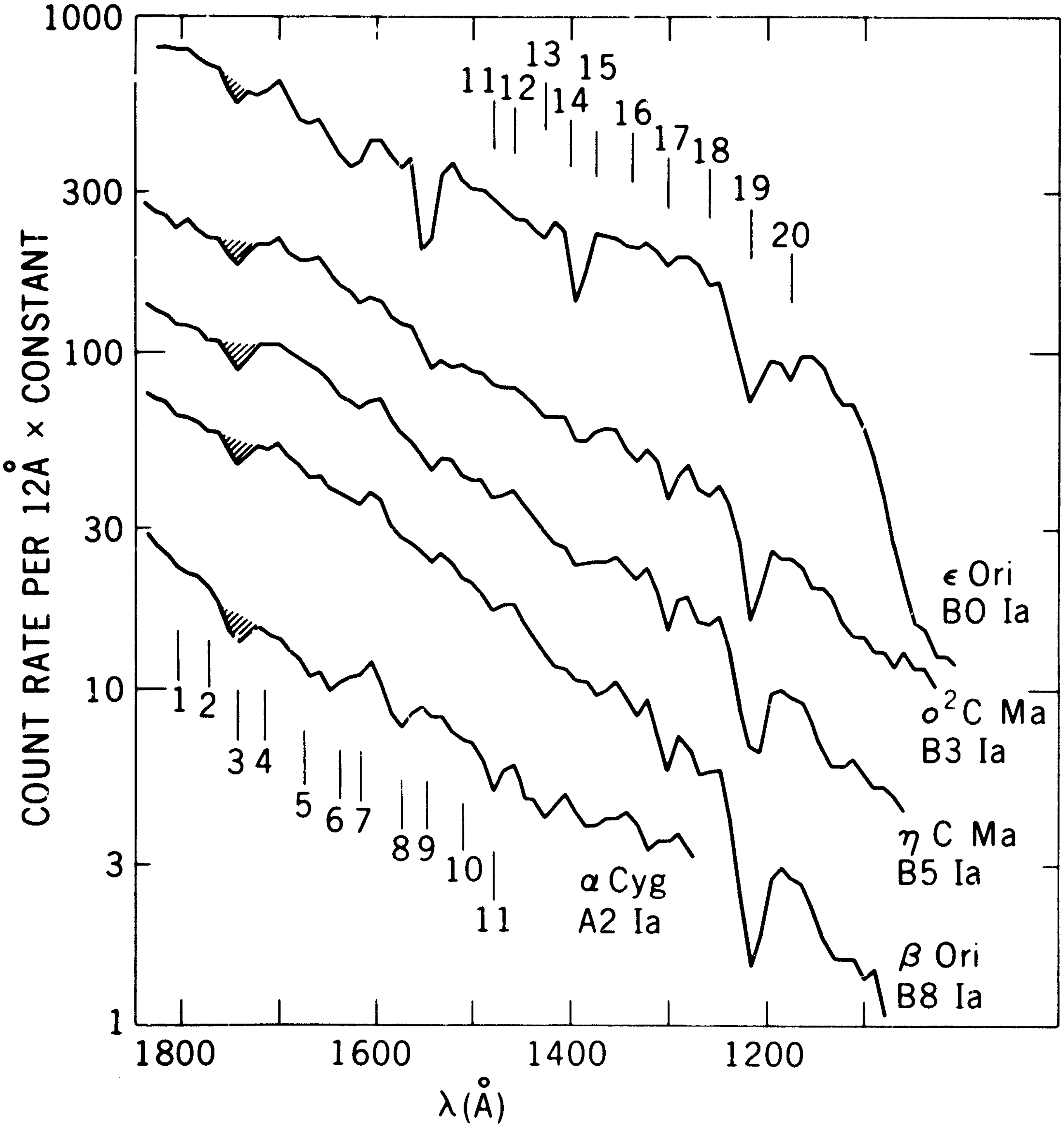
Position	Position Wavelength (Å)	Possible Contributors	Multiplet	Wavelength (Å)
17	1298	Si II	3	1304,1309
		P II	2	1302-1311
		O I	2	1302-1306
		S I	9	1296-1306
		Si III	4	1295-1303
		Mn II	6	1291,1292
		Ti III	1,2	1286-1299
		Mn III	9	1284-1292
18	1256	Fe II	9	1261-1267
		C I	9	1261-1262
		S II	1	1251-1260
		Si II	4,8	1247 1265
		C III	9	1247
		N I	5	1243
19	1214	Mn III	6	1220-1224
		H I	1	1216
		He II	13	1215
		Si IV	16	1211
		Si III	2	1207
		N I	1	1200-1201
		Mn II	3,15	1197-1201
20	1172	N III	20	1183-1185
		Mn III	7	1180-1186
		C III	4	1175-1176
		* Ga II	6	1168-1187
		N I	6,7	1164-1168
		Mn II	4	1162-1164

*We include lines of some elements of low abundance on the possibility that they may be particularly strengthened in absorption by non-LTE excitation conditions.

CAPTIONS FOR THE FIGURES

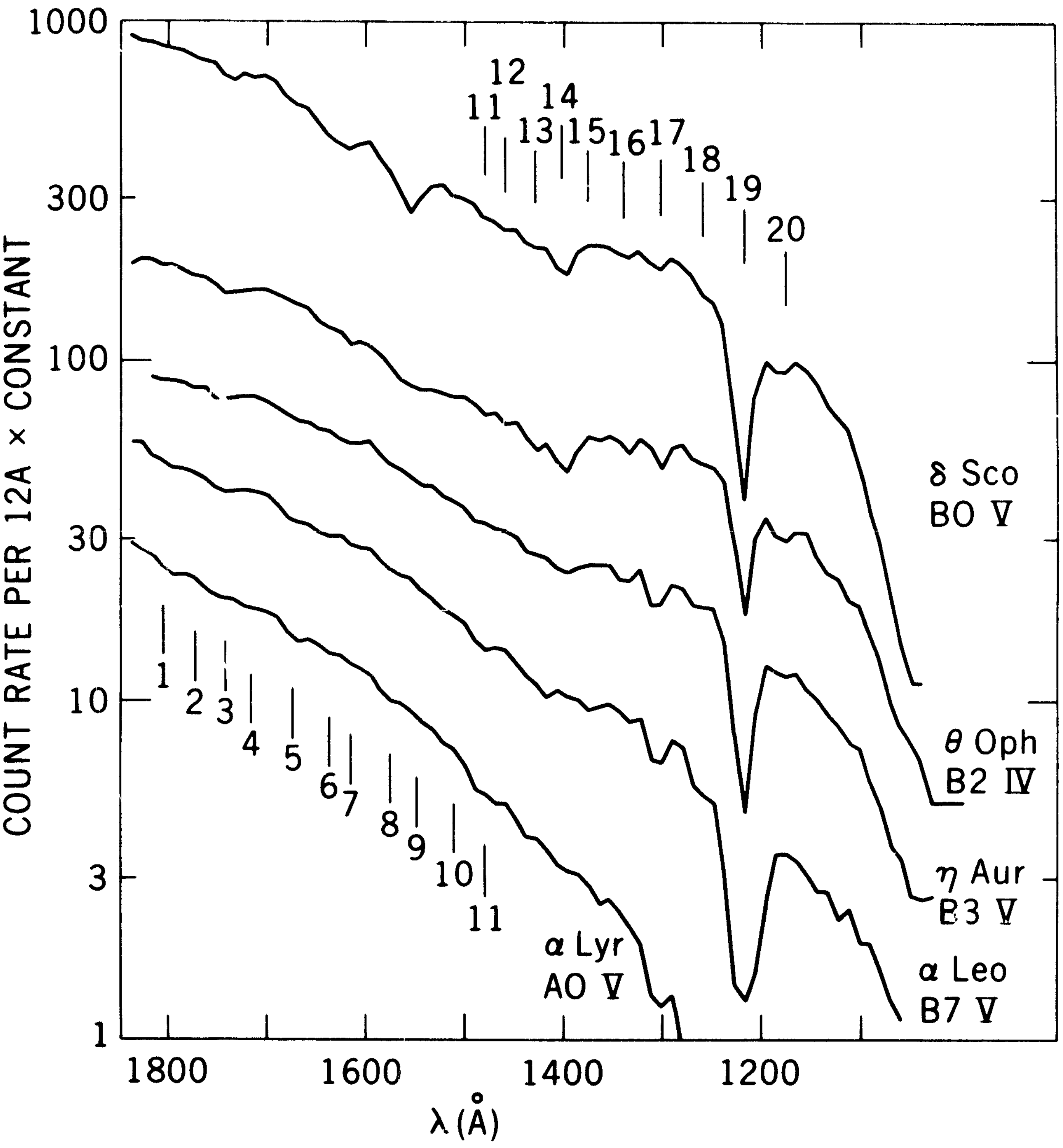
Fig. 1 - Spectrum scans of five early-type Ia supergiants. Count rates in a nominal 12Å band are multiplied by an arbitrary constant and plotted logarithmically _vs._ wavelength. Twenty positions near which prominent features occur are indicated (see Table 1). The cross-hatched feature near λ1739 is discussed in the text.

Fig. 2 - Spectrum scans of five early-type main-sequence stars. Count rates in a nominal 12Å band are multiplied by an arbitrary constant and plotted logarithmically _vs._ wavelength. Twenty positions near which prominent features occur are indicated (see Table 1).



1000
300
100
30
10
3
1
COUNT RATE PER 12Å × CONSTANT
1800
1600
1400
1200
λ(Å)
1 2
3 4
5 6 7
8 9
10
11
11 12 13 14 15 16 17 18 19 20
ϵ Ori
B0 Ia
o²C Ma
B3 Ia
η C Ma
B5 Ia
β Ori
B8 Ia
α Cyg
A2 Ia

FIGURE 1



1000
300
100
30
10
3
1
COUNT RATE PER 12Å × CONSTANT
1800
1600
1400
1200
λ(Å)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
δ Sco
BO V
θ Oph
B2 IV
η Aur
B3 V
α Leo
B7 V
α Lyr
AO V

FIGURE 2